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DECREASE OF THE $N_2(A)$ METASTABLE CONCENTRATION IN THE GAS DIODE AFTERGLOW

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Abstract: The dependencies of N(A) metastable concentration decrease on the two $N_2(A)$ metastable collision rate k_1 and on the collising rate with the atomic nitrogen k_2 in the gas diode afterglow $n_A = f(\tau)$ were investigated. A physical model of metastable deexcitation processes was proposed. The coresponding differential equations were calculated numericaly for the k_1 ranging from 10^{-8} to $10^{-12}\,cm^3s^{-1}$ and for k_2 values from 10^{-10} to $10^{-12}\,cm^3s^{-1}$, and for the afterglow times τ from 10^{-4} to $10^2\,s$. The results of this estimations are compared with the interpretation of the $\langle t_d \rangle = f(\tau)$ curve that was experimentally determined previously. The results shows that conditiones can bee found for which this metastables can exist in the gas diode tube with the significant concentrations for the afterglow priodes over 20 secondes.

1. Introduction

The interpretation of some experimental results of the mean breakdown time delay $\langle t_d \rangle$dependence on the afterglow period τ suggests a conclusion that some metastable atoms and molecules can exist in the gas diode for a long time during an afterglow. In this kind of experiments the volume of the tube is much larger then the discharge area and it seems that this fact has some influence on the long nonradiative life-time of the metastables. In the present paper a simple kinetic model was used in order to explain the $N_2(A)$ concentration decrease in the afterglow at $13.3\,mbar$ pressure of nitrogen. The influence of the two $N_2(A)$ molecules collision rate and the collision rate of $N_2(A)$ molecule with the atomic nitrogen, on the decrease of concentration of the molecular metastables $N_2(A)$, atomic nitrogen N(S) and the electrons in the center of the diodes gap, was calculated numerically. The results are compared with the interpretation of the $\langle t_d \rangle = f(\tau)$ curve that was found experimentally [6].

2. Kinetic model

Basic features of this model were presented earlier [8]. The gas diode tube of a cylindrical shape with the volume of about $100\,cm^3$ with a spherical electrodes of $1\,cm$in diameter

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was presumed. The electrodes are located in the center of the tube and the interelectrode gap is $3\,mm$.The tube is filled with $13.3\,mbar$ of pure nitrogen and the discharge , with the current of about $0.5\,mA$, is located in the gap (according to relation: $p \cdot d > p \cdot d_{min}$). This kind of diode was used in the real experiments [6]. The metastable $N_2(A)$ molecules that are created in the discharge diffuse to all other parts of the tube. In the stationary regime a number that arrives to any part of the tube volume is balanced by the losses mainly by collisions in the gas and on the tube walls or electrode surfaces . The concentration distribution in the stationary regime was calculated earlier [7] and was used for the concentration decreasing estimations. The kinetic equation is of the form:

$$\frac{\partial N_A}{\partial t} = D_A \nabla^2 n_A - k_1 n_A^2 - k_2 n_A n_S + k_3 n_S^2 n_X - k_4 n_A n_I - \frac{n_A}{\tau'} - E_{r,z} n_A - W_{r,z} n_A \quad (1)$$

where n_A,n_S, n_X and n_I stands for $N_2(A)$, N(S), $N_2(X)$ and impurity concentrations respectively. The corresponding rate coefficients were $k_3 = 2.4 \cdot 10^{33}\,cm^6 s^{-1}$, $k_4 = 1 \cdot 10^{-14}\,cm^3 s^{-1}$ (according to [2] and [3]) while the values of k_1 were varied from 10^{-8} to $10^{-11}\,cm^3 s^{-1}$ and the values of k_2 from 10^{-10} to $10^{-12} cm^3 s^{-1}$. The $D_A$is the $N_2(A)$ molecule diffusion constant with the value of $16.7 cm^2 s^{-1}$ at $13.3\,mbar$ pressure [1] and the radiative life-time $\tau' = 12.5\,s$. In this equation the coefficients $E_{r,z}$ and $W_{r,z}$ represent the deexcitation rates in collision with the electrode and wall surfaces and they were calculated earlier [7]. The estimation was done for the $300\,K$temperature. The γ_W and $\gamma_E$stand for the $N_2(A)$ metastable deexcitation probabilities in collision with the glass wall and the electrode surfaces with the value of $3 \cdot 10^{-5}$ and $5 \cdot 10^{-3}$ respectively [4,5]. As n_S and the concentration of the charged particles also depends on the time (and coordinates) the additional two equations were applied:

$$\frac{\partial n_S}{\partial t} = D_S \nabla^2 n_S - k_3 n_S^2 n_X + k_5 n_e^2 \quad (2a)$$

and

$$\frac{\partial n_e}{\partial t} = D_a \nabla^2 n_e - k_5 n_e^2 + E_e(r,z) \cdot n_e \quad (2b)$$

where k_5 is the recombination rate coefficient with the value of $1 \cdot 10^{-9} cm^3 s^{-1}$, D_S is the atomic nitrogen diffusion coefficient with the values of $30\,cm^2 s^{-1}$, D_a is the ambipolar diffusion coefficient with the values of $100\,cm^2 s^{-1}$ and the E_e is the rate coefficient of electrode processes and is the function of coordinates. This system of equations was solved numerically using step by step procedure.

3. Results

The results of these calculations are presented in figures 1 and 2. The influence of the collision rate k_1 for the values from 10^{-10} to $10^{-8}\,cm^3 s^{-1}$are presented on fig. 1. In this estimation k_2 was constant with the value $5 \cdot 10^{-11}\,cm^3 s^{-1}$. In the same figure the results of calculations of the atomic nitrogen and the charged particle concentration decrease are also presented. This results show that electrons vanished in the time $\tau < 50\,ms$ that depends on the n_e concentration in the stationary discharge and the recombination rate, and that concentration of the atomic nitrogen n_S never exceeds $500\,ms$ time in significant concentrations. The results of this estimation are compared with the interpretation of

the time-delay $t_d$measurements in afterglow regime of the diode and other experimental conditions similar to those taken for the present physical model. The comparison was possible since the statistical theory of the electrical breakdown which relates the mean value of the statistical time-delay $\langle t_S \rangle$ with the concentration of the primary ionization N_o in the gap, $\langle t_S \rangle \sim 1/N_o$. Further presumption is that the primary ionization, for the long afterglow periods τ, is dominantly produced by the surface processes and thus is proportional with the $N_2(A)$ metastables concentrations. So, the following relation can bee written: $\langle t_S \rangle \sim \langle t_d \rangle = C_1/n_A$ and otherwise: $n_A \sim \langle t_d \rangle^{-1}$. From fig. 1 it can be seen that, for the $\tau < 10^{-2}s$, there is a qualitative disagreement between the behavior of the interpreted experimental values (assigned in fig.1 with triangles) and the calculated n_A values regardles on the rate coefficient k_1 values. It is obvious that this kind of experiments are somehow limited to this small afterglow periods.

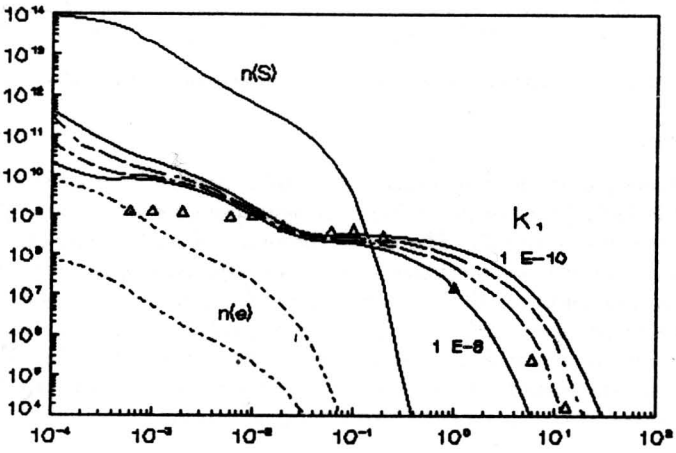

FIGURE 1 *The $N_2(A)$,N(S) and n_e concentrations decrease in afterglow, $N_2(A)$ concentrations decrease for the different k_1 values.*

Both the $\langle t_d \rangle^{-1}$ and the calculated curves have some plateous (local saturations) for the τ values from about 20 to 200 ms. The assumption (according to the results of these estimations) was that these plateous are caused by the change from the diffusion to the back-diffusion of the $N_2(A)$ molecules that diffuse from the other parts of the diode tube to the diode gap, where the faster deexcitation on the electrode surfaces occur. It seems that the best agreement with the interpreted experimental results is obtained for the curve with k_1 value $6 \cdot 10^{-9}\, cm^3 s^{-1}$, which is somewhat greater value that it was assumed earlier [2].

The influence of the rate constant k_2 on the n_A decrease is presented in fig. 2. The calculations were carried out for $k_1 = 1.1 \cdot 10^{-9}\, cm^3 s^{-1}$, $\gamma_E = 0.003$ and for the k_2 values ranging from $2 \cdot 10^{-12}$ to $3 \cdot 10^{-10}\, cm^3 s^{-1}$. The results show that this decay mechanism is dominant for $\tau < 200\, ms$, when the concentrations of the atomic nitrogen is still high. The best fit with the $\langle t_d \rangle^{-1}$ values has the curve for $k_2 = 5.5 \cdot 10^{-11}\, cm^3 s^{-1}$, which is in agreement with the k_2 value cited in [4].

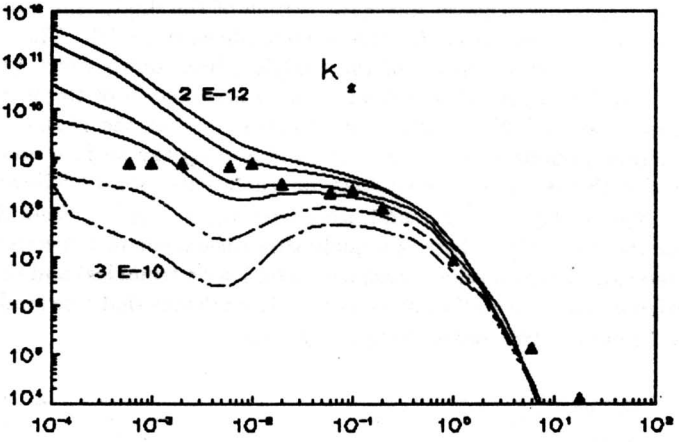

FIGURE 2 *The calculated decrease of the $N_2(A)$ concentration for the different k_2 values.*

4.Conclusions

In the present paper the simple physical model is derived in order to explain the existence of the $N_2(A^3\Sigma_u^+)$ molecules in high concentrations for a long afterglow periods, as it was suggested previously [6]. The model comprises of some dominant $N_2(A)$ metastables creation and destruction mechanisms in the gas afterglow at 13.3 *mbar* preassure. The comparison of these results with the interpretation of the experimentally determined values of $\langle t_d \rangle$ for the similar diode and other conditions suggest the conclusion that the afterglow period of interest for this model representation is 10^{-2} up to 10^2 *s*. The results show that conditiones can bee found for which the metastables can exist in the gas diode tube with the significant concentrations for the long afterglow periods.

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OPADANJE KONCENTRACIJE METASTABILNIH $N_2(A)$ MOLEKULA GASNOJ DIODI NAKON PRESTANKA PRAŽNJENJA

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Sadržaj: U radu je istraživan uticaj kolizionih faktora za sudar dva metastabilna molekula azota u $N_2(A)$ stanju k_1 kao i sudara metastabilnog molekula azota sa atomarnim azotom k_2 na opadanje koncentracije metastabilnih $N_2(A)$ molekula azota u medjuelektrodnom prostoru gasne diode nakon prestanka pražnjenja. Numerički proračun je vršen za k_1 vrednosti od 10^{-8} do $10^{-12}\,cm^3s^{-1}$, za k_2 vrednosti od 10^{-10} do $10^{-12}\,cm^3s^{-1}$, a za posleprobojna vremena τ od 10^{-4} do 10^2 sekundi. Rezultati proračuna su uporedjeni sa interpretacijom eksperimentalno odredjene zavisnosti $\langle t_d \rangle = f(\tau)$ date ranije [6] što je ukazalo da se mogu naći uslovi pod kojima metastabilni molekuli azota mogu postojati u balonu gasne diode relativno dugi vremenski period nakon prestanka pražnjenja.